The Center for Astrophysical Thermonuclear Flashes

The Legacies of the Flash Center: Transforming Science and Institutions

Don Q. Lamb

ASC PI Meeting
9 February 2010

(http://flash.uchicago.edu)

An Advanced Simulation and Computation (ASC)
Academic Strategic Alliances Program (ASAP) Center
at The University of Chicago

Our starting ambitions were three-fold …

- **Achieve significant science impact**
  - ‘Flash’ astrophysics
  - Computational (astrophysical) hydrodynamics/mhd
  - Computer science and applied mathematics
- **Transform computational science at UofC and Argonne**
  - Build the community of computationally-savvy scientists at the UofC
  - Institutionalize the presence of computational science (and high-performance computing in particular) at UofC by creating a university faculty structure for training of students and postdocs
  - Strengthen Argonne’s computer science program by connecting it to a world-class ‘applications’ group
- **Transform the perception of UofC itself, and its relationship with Argonne – both internally and externally**
  - Put UofC ‘on the map’ in computational science, especially in computational astrophysics and hydrodynamics/mhd
  - Demonstrate by example the utility of UofC/Argonne collaboration

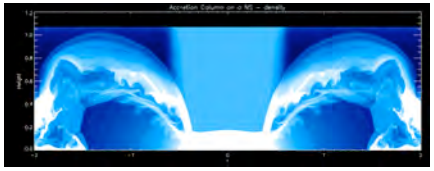
Given the level of effort, we demanded of ourselves transformational legacies

"FLASH" was both a goal and a tool …

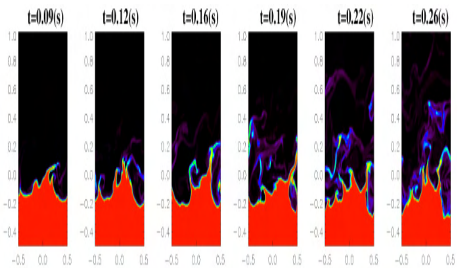
- We early on realized that high performance computing - and the simulations that it makes possible - is not (just) about producing beautiful images, can be a powerful tool for exploring new ideas, building 'physical intuition' for highly complex (in terms of both physics and mathematics) astrophysical problems, and connecting the results of new concepts quantitatively to extant observations
- Turning '*can be*' into '*is*' was our challenge
  - Building a widely-deployed community code for astrophysical fluid dynamics and magnetohydrodynamics was the means
  - Sustaining the effort against a great deal of skepticism was a core challenge

Thus, FLASH has ended up being both a tool for creating legacies, and a legacy in its own right

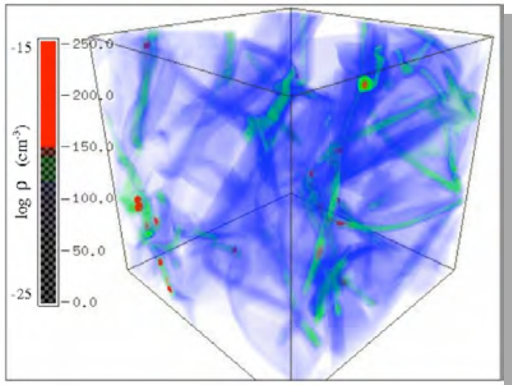
FLASH capabilities span a broad range …



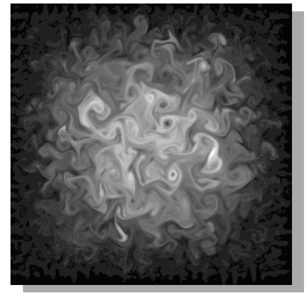
Relativistic accretion onto NS



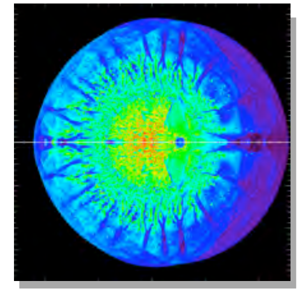
Wave breaking on white dwarfs



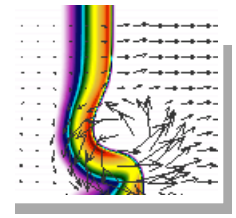
Gravitational collapse/Jeans instability



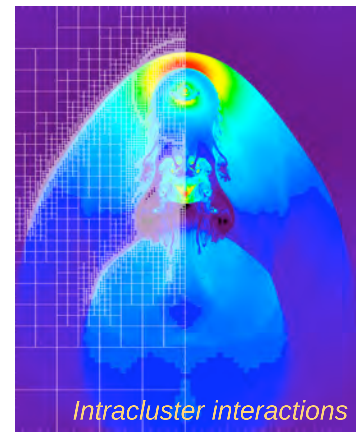
Compressed turbulence



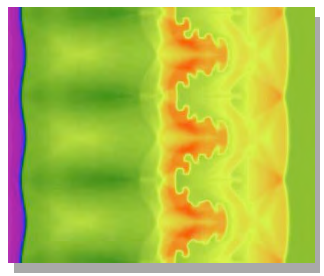
Type Ia Supernova



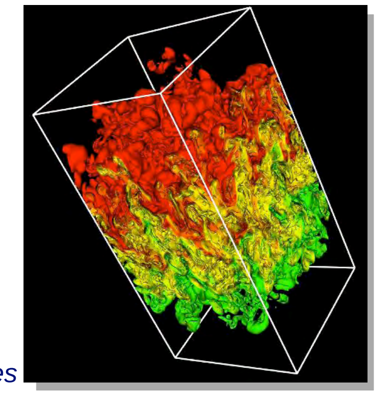
Flame-vortex interactions



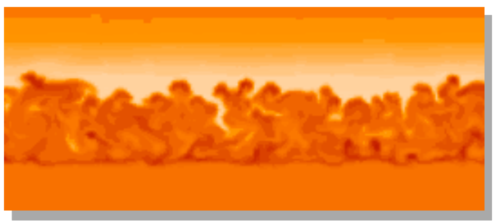
Intracluster interactions



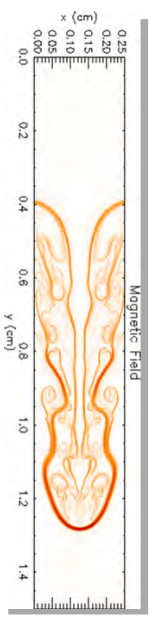
Laser-driven shock instabilities



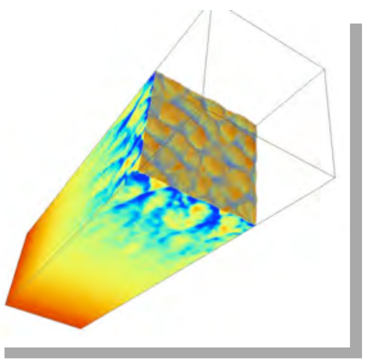
Rayleigh-Taylor instability



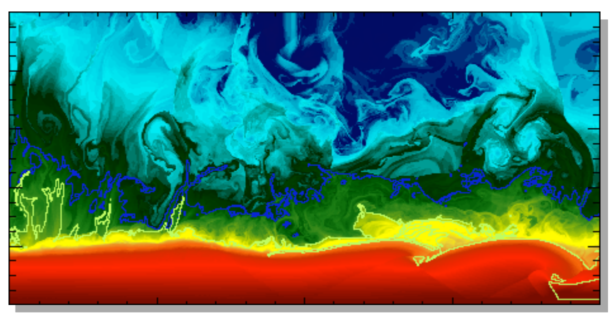
Nova outbursts on white dwarfs



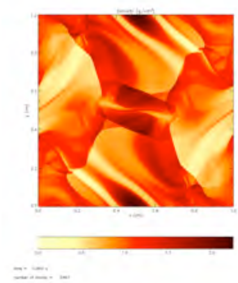
Magnetic Rayleigh-Taylor



Cellular detonation



Helium burning on neutron stars



Orzag/Tang MHD vortex

Richtmyer-Meshkov instability

… FLASH is used by groups throughout the world

Munich University Observatory
CAST
Computational Astrophysics Group

Germany

http://www.usm.uni-muenchen.de/CAST/people.html
Pawel Ciecielag: Planets formation: planetesimals accretion, gas drag, disk-planet interaction; Cosmology: large scale velocity fields, density-velocity comparisons; Numerical methods: direct n-body (Nbody4++ code, special purpose hardware - GRAPE), hydro (PPM, AMR, FLASH code).
Steffi Walch: Star formation with emphasis on the formation of protostellar disks, evolution and fragmentation of protoplanetary disks and the evolution of their spectral energy distributions. Numerical Methods: hydrodynamics (FLASH code)

Practical FLASH Notes 10/14/2005 04:14 PM

Learning and Testing FLASH: Practical Notes

This page is intended for members of the Computational Astrophysics group at McMaster University who whish to learn and be involved with the testing of the FLASH code. The code was developed at the ASCI/Alliances Center for Astrophysical Thermonuclear Flashes at the University of Chicago.

Getting Started:

Canada

…step spoon-feed for …s along the way.

THE FLASH CODE AT OAPA 10/14/2005 01:21 PM

OSSERVATORIO ASTRONOMICO DI PALERMO GIUSEPPE S. VAIANA

The FLASH code at OAPA

Italy

The Osservatorio Astronomico di Palermo is one of the test sites for the very accurate FLASH code, a 3-dimensional astrophysical hydrodynamic code for supercomputers mainly developed at the "Flash Center", the University of Chicago.

Palermo is the test site in which FLASH has been ported to Compaq architectures. The FLASH code solves the compressible Euler equations on a block-structured adaptive mesh, and its modular design permits the introduction of additional physics and of different solvers.

The Palermo team collaborates with the Flash Center to upgrade and to apply extensively FLASH to astrophysical systems.

The group in Palermo also develops new modules for FLASH which extend the field of applicability of the code to other problems in astrophysics, from solar and stellar coronae, to supernova remnants, and to galaxy clusters halos. In particular, the new modules so far developed and tested include:

1. the non-equilibrium ionization effects of the most abundant elements in astrophysical plasmas
2. the thermal conduction according to the formulation of Spitzer (1962)
3. the radiative losses from an optically thin plasma according to the Raymond spectral code and Peres et al. (1982) for the chromosphere.
4. the viscosity according to the formulation of Spitzer (1962)

In this project, the Palermo team takes advantage of its long experience in developing hydrodynamic codes for modeling astrophysical plasma and in optimizing the codes for efficient parallel execution on high performance computers. The group has recently acquired and uses, for the FLASH development, a high performance computing (HPC) cluster of 16 powerful alpha EV67 processors distributed in 4 compaq ES40 (interconnected with a highly efficient Memory Channel II), entirely dedicated to HPC projects (for more information see the SCAN facility homepage).

http://www.astropa.unipa.it/FLASH/ Page 1 of 1

US

The Astrophysical Journal, 628:205–209, 2005 July 20

SUPERNOVA BLAST WAVES IN LOW-DENSITY HOT MEDIA: A MECHANISM FOR SPATIALLY DISTRIBUTED HEATING

Shikui Tang and Q. Daniel Wang
Department of Astronomy, University of Massachusetts, LGRT-B 619E, 710 North Pleasant Street, Amherst, MA 01003; tangsk@astro.umass.edu, wqd@astro.umass.edu
Received 2004 December 17; accepted 2005 April 11

ABSTRACT

Most supernovae are expected to explode in low-density hot media, particularly in galactic bulges and elliptical galaxies. The remnants of such supernovae, although difficult to detect individually, can be profoundly important in heating the media on large scales. We characterize the evolution of this kind of supernova remnant, based on analytical approximations and hydrodynamic simulations. We generalize the standard Sedov solution to account for both temperature and density effects of the ambient media. Although cooling can be neglected, the expansion of such a remnant deviates quickly from the standard Sedov solution and asymptotically approaches the ambient sound speed as the swept-up thermal energy becomes important. The relatively steady and fast expansion of the remnants over large volumes provides an ideal mechanism for spatially distributed heating, which may help to alleviate the overcooling problem of hot gas in groups and clusters of galaxies, as well as in galaxies themselves. The simulations were performed with the FLASH code.

Subject headings: cooling flows — galaxies: clusters: general — galaxies: ISM — ISM: structure — supernova remnants

Online material: color figures

CITA–ICAT
ABOUT THE INSTITUTE
RESEARCH @ CITA
WORKING @ CITA
EVENTS & CALENDAR
Archive
Seminars
Lunch Talks
Meetings &

10/14/2005 01:30 PM

FLASH Code Development

…m Members:

…n Boss (DTM)
…abeth Myhill, Justin Domes (Marymount University)
…ri Vanhala (Challenger Center)

US

…e FLASH Adaptive Mesh Refinement Hydrodynamics Code

…seek to study the dynamics of mixing and transport processes in the presolar cloud and in the solar …ula, in the context of isotopic heterogeneity introduced either by shock-triggered collapse of the presolar …d or by infall from an x-wind outflow, the two leading explanations for the widespread evidence of …t-lived radioactivities in chondritic refractory inclusions and, much more rarely, in chondrules. Myhill … Domes are leading our effort to develop a new hydrodynamical code for studying these problems, the …SH adaptive mesh refinement code. FLASH will allow the problem of shock-wave triggering and …tion to be studied with an unprecedented degree of high spatial resolution, which is likely to be critical …e question of simultaneous triggering and injection when nonisothermal shock front thermodynamics is …loyed. We will work with Vanhala to define a nonisothermal shock test case to be calculated with both …FLASH code and Vanhala's EVH-1 code. In addition, the FLASH code will permit extending these …stigations down to the scale of the solar nebula, where nebular transport and mixing processes can be …ied in general terms, applicable to isotopically heterogeneous grains falling onto the nebular surface as a …lt of either shock-triggered collapse or x-wind outflows. We will seek in part to learn whether spatial … temporal heterogeneity inherited from such sources can survive subsequent nebular mixing processes … can help to explain certain isotopic abundance patterns seen in the inner Solar System and the asteroid … The development of the FLASH code should also prove useful for Boss's studies of the formation of …t planets by the disk instability mechanism.

3D AMR Simulations of Point-Symmetric Nebulae

Erik-Jan Rijkhorst, Vincent Icke, and Garrelt Mellema, Sterrewacht Leiden, The Netherlands
http://www.strw.LeidenUniv.nl/AstroHydro3D/

Numerical Implementation

We used the three-dimensional hydrocode *Flash* [6] to model the interaction between a spherical wind and a warped disk. This parallelized code implements block-structured adaptive mesh refinement (AMR) [7] (see images below) and a PPM type hydrosolver [8].

We added to the code the proper initial conditions for the wind-di… warped disk, Eq. (1) was combined with a constant 'wedge angle… was given a constant density . The spherical wind was implemen… $1/r^2$ density profile and a constant velocity. The pressure was cal… constant Poisson index γ.

Netherlands

Monthly Notices of the Royal Astronomical Society
Volume 355 Issue 3 Page 995 - December 2004
doi:10.1111/j.1365-2966.2004.08381.x

UK

Quenching cluster cooling flows with recurrent hot plasma bubbles
Claudio Dalla Vecchia[1], Richard G. Bower[1], Tom Theuns[1,2], Michael L. Balogh[1], Pasquale Mazzotta[3] and Carlos S. Frenk[1]

EVENTS & CALENDAR

FLASH Workshop

Canada

Workshop
Wed, Mar 23, 2005, 9:00 AM
Location: MP1318A

Workshop on the FLASH code: a general-purpose, parallel, adaptive mesh, reactive astrophysical hydrodynamics code that is available to the research community

Tentative Schedule

Abstract:

On March 23 and 24th, CITA will host a mini-workshop on the FLASH code: a general-purpose, parallel, adaptive mesh, reactive astrophysical hydrodynamics code that is available to the research community. The FLASH code has been applied to problems from burning in or on compact objects, to the efficiency of cooling flows in galaxy clusters, to cosmological simulations.

Four people will be coming from the Chicago FLASH centre to give one day of talks on the capabilities of the code, and will be available to schedule meetings with on the second day for more focused, less formal discussions on applying the FLASH code to problems of interest to local projects.

The Astrophysical Journal, 630:740–749, 2005 September 10

Germany

ACTIVE GALACTIC NUCLEI HEATING AND DISSIPATIVE PROCESSES IN GALAXY CLUSTERS

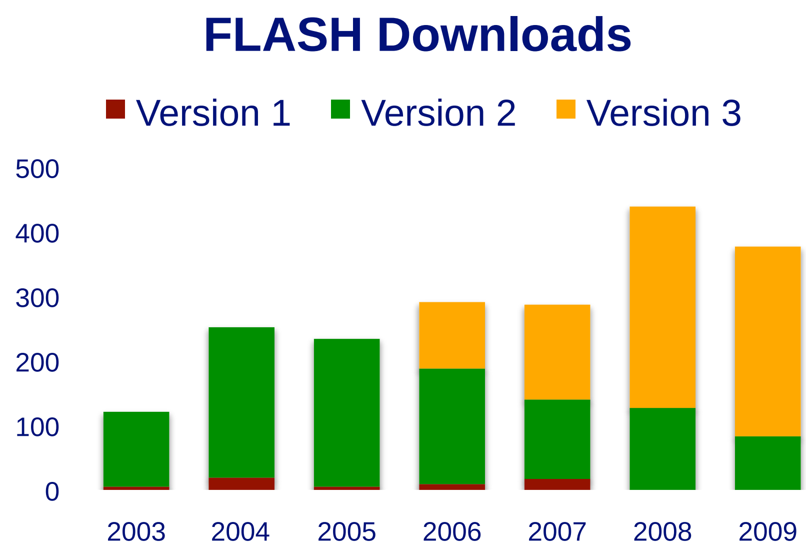
M. Brüggen
International University Bremen, Campus Ring 1, 28759 Bremen, Germany; m.brueggen@iu-bremen.de
M. Ruszkowski[1]
Joint Institute for Laboratory Astrophysics, Campus Box 440, University of Colorado, Boulder, CO 80309-0440; mr@quixote.colorado.edu
and
E. Hallman
Center for Astrophysics and Space Astronomy, University of Colorado, Boulder, CO 80309; hallman@origins.colorado.edu
Received 2005 January 10; accepted 2005 May 22

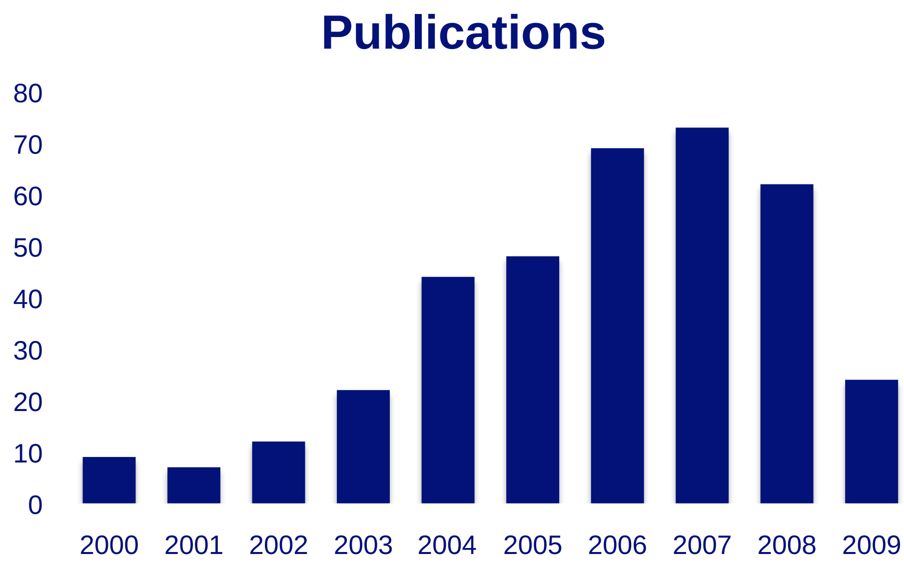
ABSTRACT

Recent X-ray observations reveal growing evidence for heating by active galactic nuclei (AGNs) in clusters and groups of galaxies. AGN outflows play a crucial role in explaining the riddle of cooling flows and the entropy problem in clusters. Here we study the effect of AGNs on the intracluster medium in a cosmological simulation using the adaptive mesh refinement FLASH code. We pay particular attention to the effects of conductivity and viscosity on the dissipation of weak shocks generated by the AGN activity in a realistic galaxy cluster. Our three-dimensional simulations demonstrate that both viscous and conductive dissipation play an important role in distributing the mechanical energy injected by the AGNs, offsetting radiative cooling and injecting entropy to the gas. These processes are important even when the transport coefficients are at a level of 10% of the Spitzer value. Provided that both conductivity and …ty are suppressed by a comparable amount, conductive dissipation is likely to dominate over viscous dissipation. …heless, viscous effects may still affect the dynamics of the gas and contribute a significant amount of dissipation …red to radiative cooling. We also present synthetic *Chandra* observations. We show that the simulated buoyant …s inflated by the AGN, and weak shocks associated with them, are detectable with the *Chandra* observatory.

…t *headings:* cooling flows — galaxies: active — galaxies: clusters: general — X-rays: galaxies

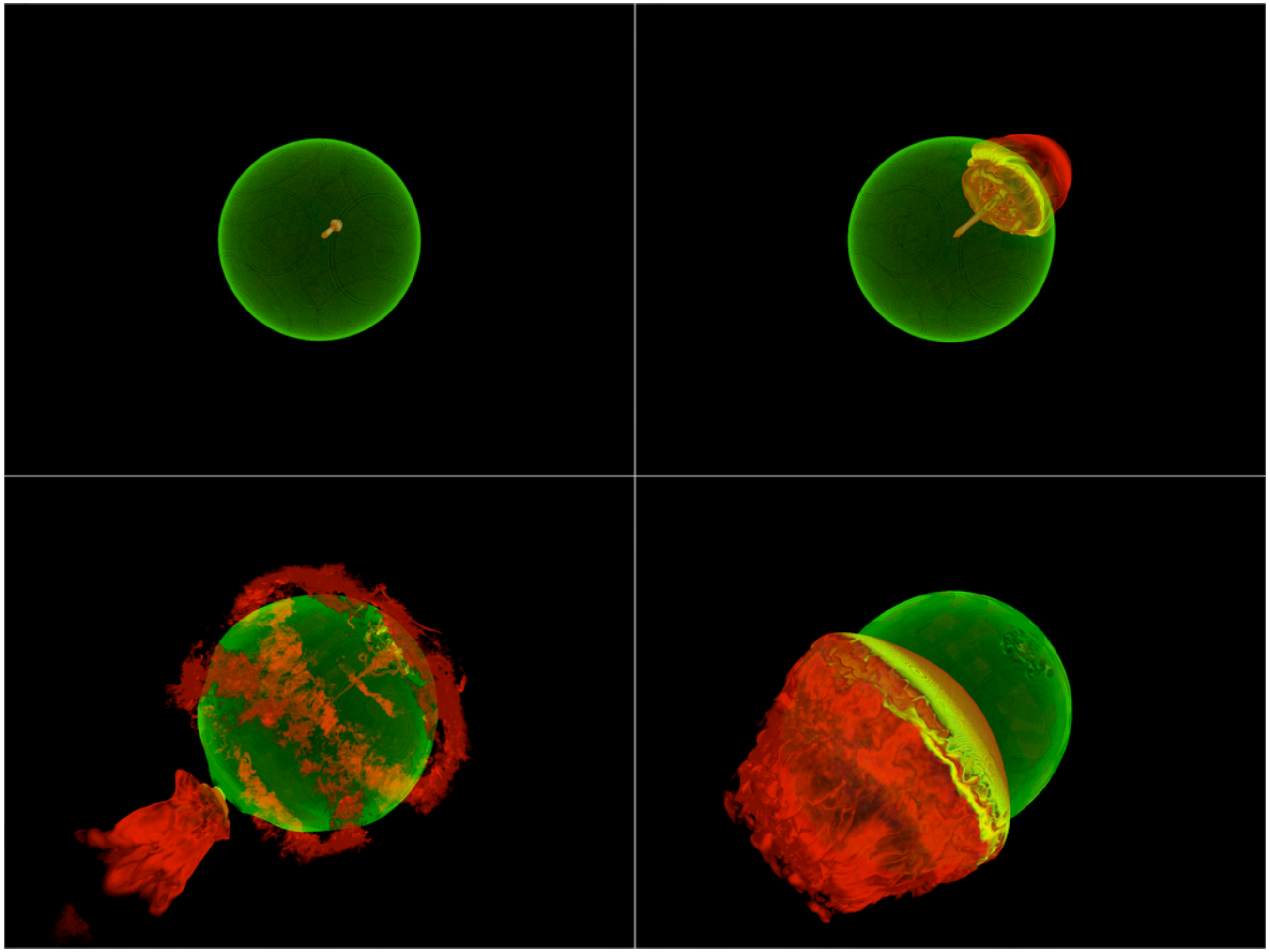
FLASH Users





- FLASH has been downloaded more than 2000 times
- More than 650 scientists have been co-authors on more than 370 papers published using FLASH

Discovery of Entirely New Mechanism for SN Ia: Gravitationally Confined Detonation



Calder et al. (2003); Plewa, Calder and Lamb (2004); Townsley et al. (2007); Jordan et al. (2008); Meakin et al. (2009)

The Center for Astrophysical Thermonuclear Flashes

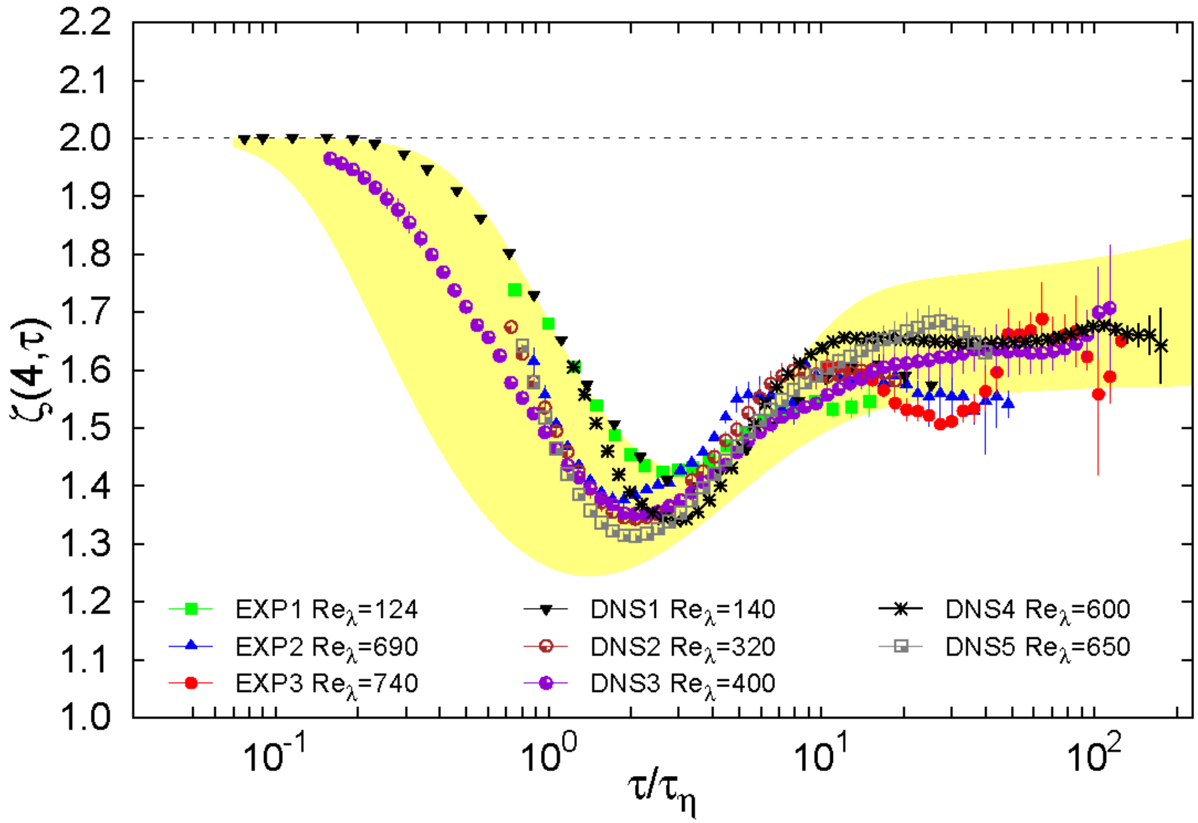
Simulation of the Deflagration and Detonation Phases of a Type Ia Supernovae

30 initial bubbles in 100 km radius.
Ignition occurs 80 km from the center of the star.
Hot material is shown in color and stellar surface in green.

This work was supported in part at the University of Chicago by the DOE NNSA ASC ASAP and by the NSF. This work also used computational resources at LBNL NERSC awarded under the INCITE program, which is supported by the DOE Office of Science.

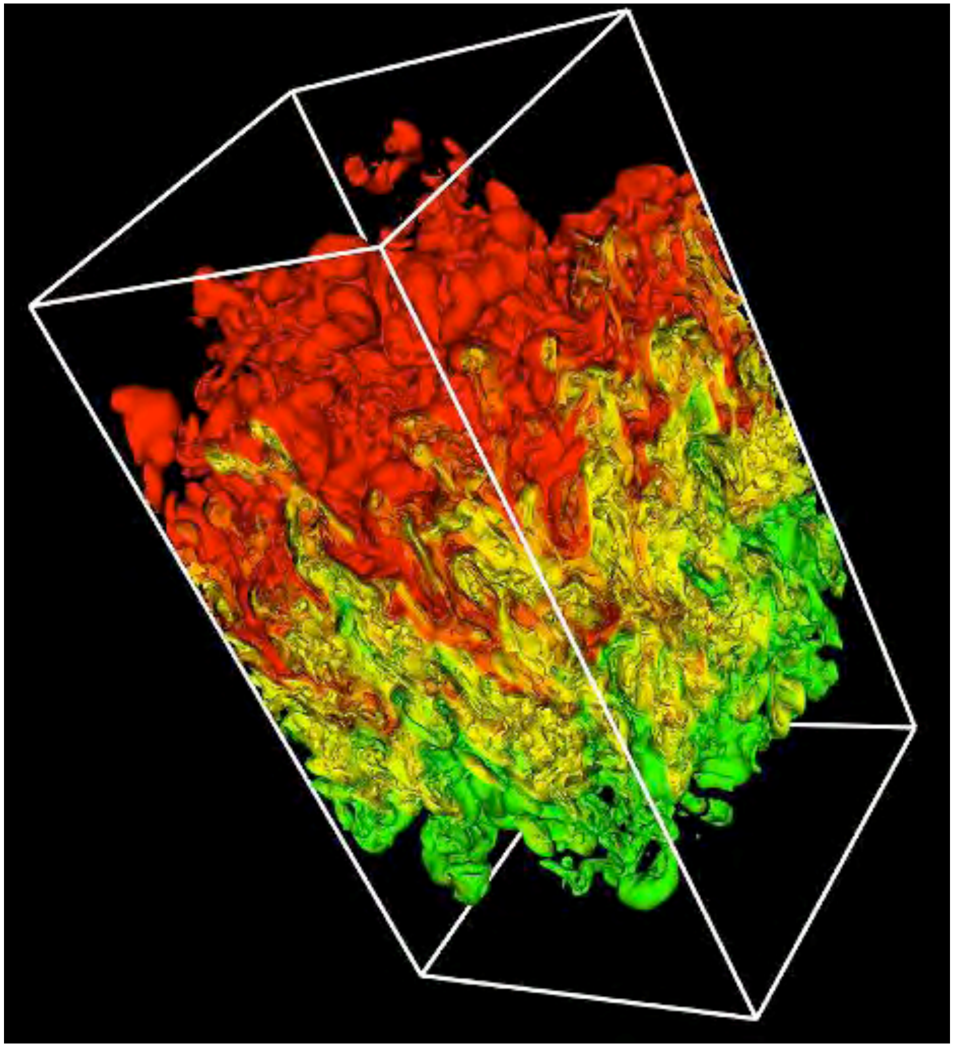
An Advanced Simulation and Computation (ASC) Academic Strategic Alliances Program (ASAP) Center at The University of Chicago

3D Simulations of Isotropic, Homogeneous, Weakly Compressible Turbulence



- Discovery of scaling behavior for density and temperature fluctuations in weakly compressible turbulent flows *(Benzi et al., PRL, 2008)*
- Demonstration of universality of statistical properties of particle trajectories in turbulent flows *(Lanotta et al., PRL, 2008)*

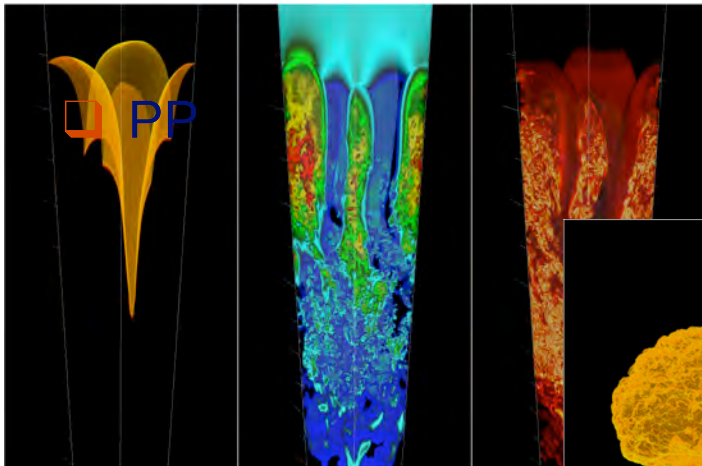
3D Simulations of Rayleigh-Taylor Instability



Dimonte et al. (2007)

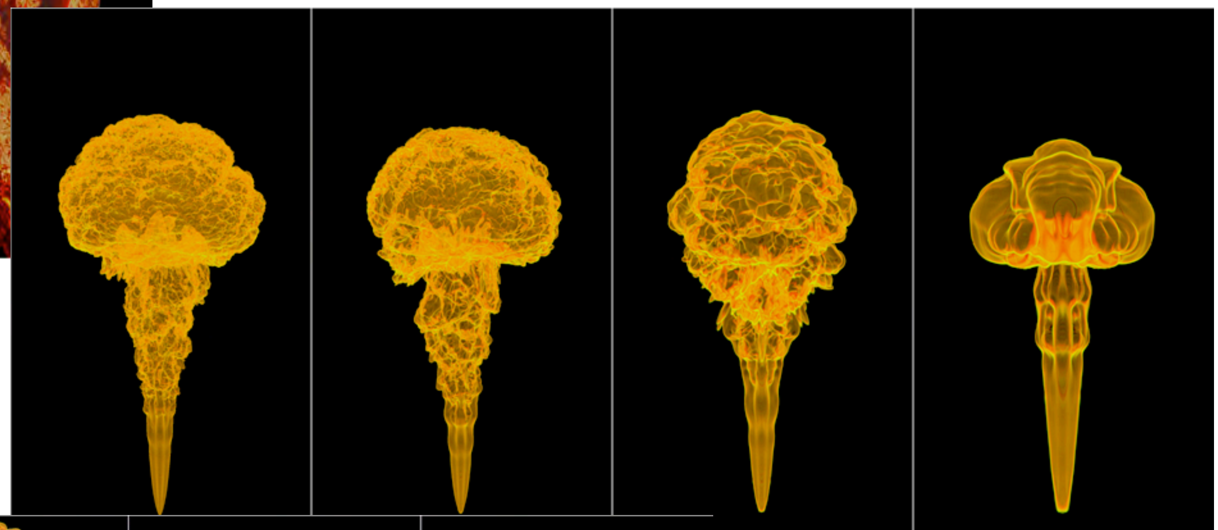
- "Alpha project" compared experiment with simulations carried out with variety of codes
- Results demonstrated that, without ability to carefully control initial conditions, experiments and simulations are ill-posed
- Results failed to demonstrate alpha (which characterizes rate of growth of mixed region) is universal

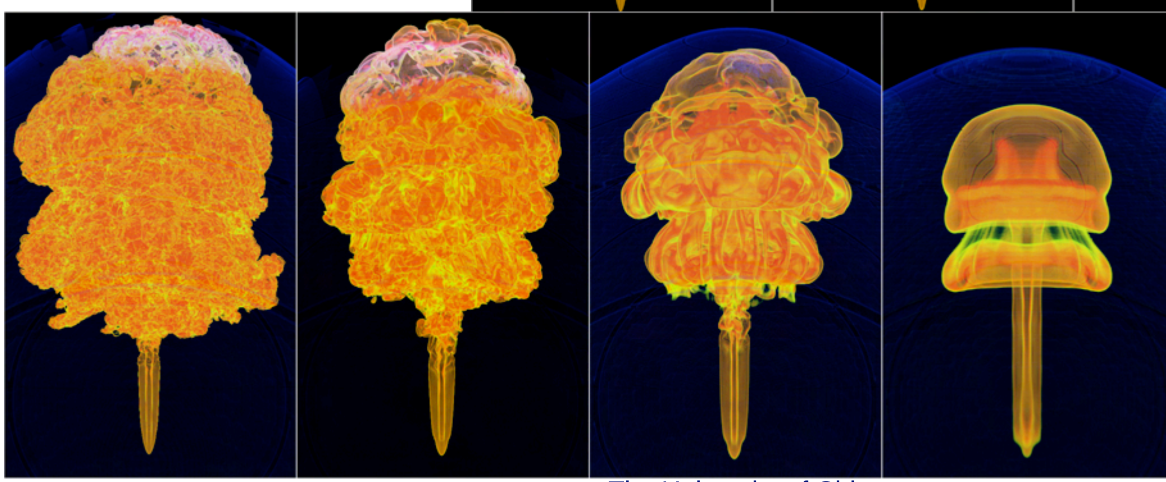
3D Verification Simulations of Buoyancy-Driven Turbulent Nuclear Combustion



Initially Planar Flame
In Rectilinear Domain
at Constant *g* and *ρ*

Flame Bubble in Rectilinear
Domain at Constant *g* and *ρ*





Flame Bubble
in White Dwarf Star

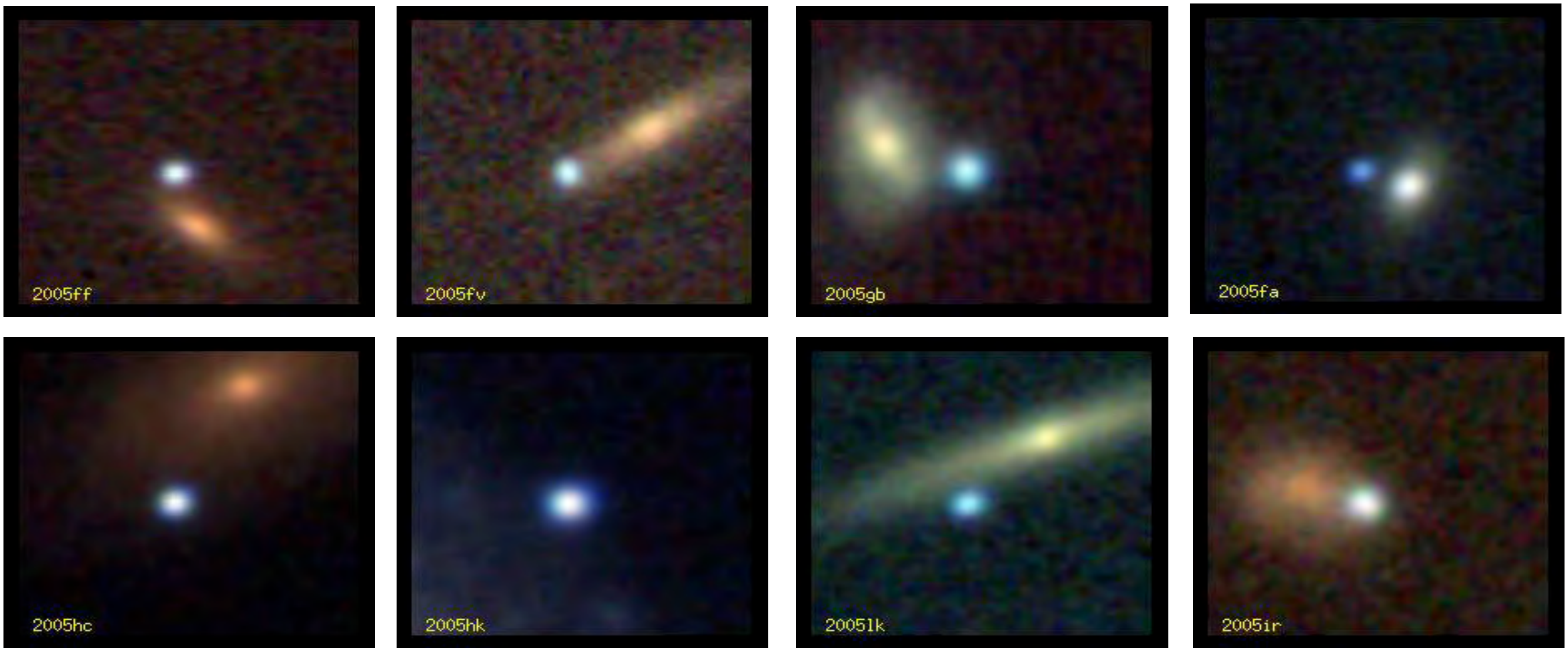
The Center for Astrophysical Thermonuclear Flashes

Simulation of Buoyancy-Driven Turbulent Nuclear Burning for a Froude Number of 0.010

This work was supported in part at the University of Chicago by the DOE NNSA ASC ASAP and by the NSF. This work also used computational resources at LBNL NERSC awarded under the INCITE program, which is supported by the DOE Office of Science.

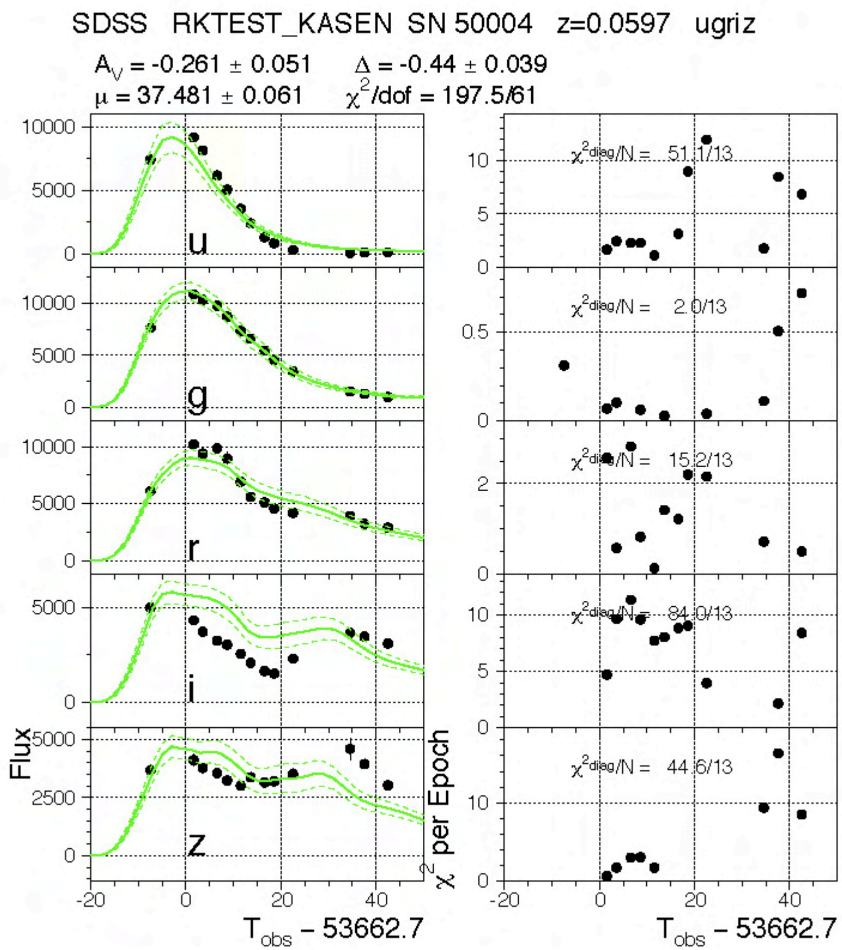
An Advanced Simulation and Computation (ASC)
Academic Strategic Alliances Program (ASAP) Center
at The University of Chicago

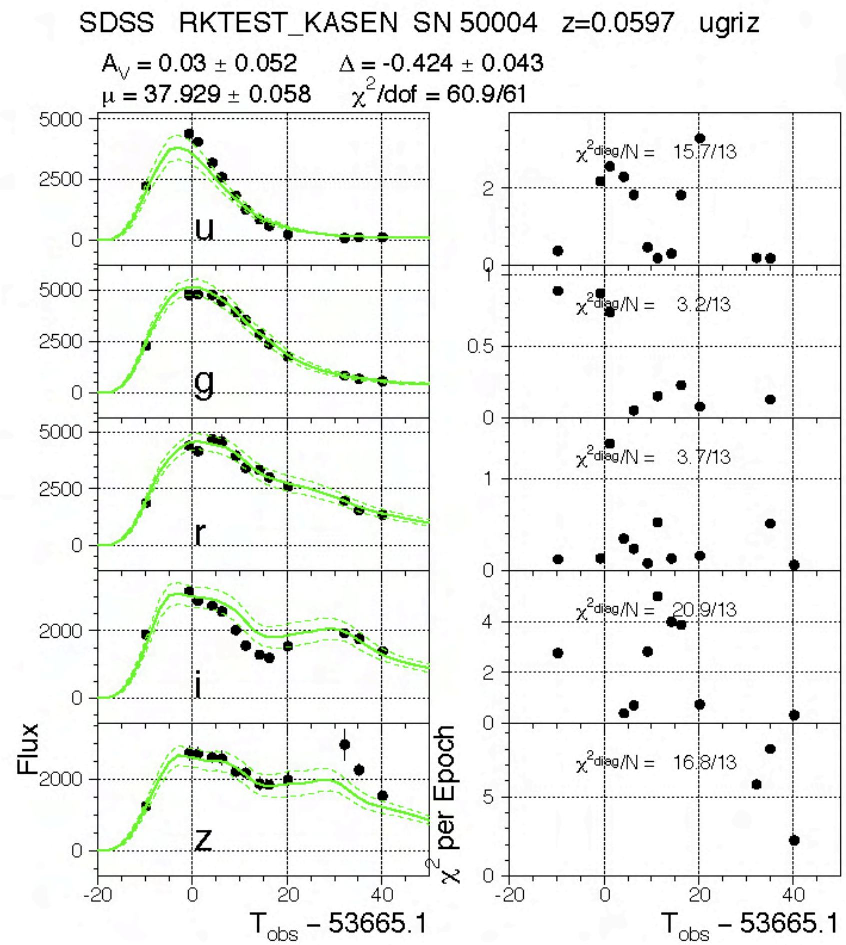
Formed Partnership with SDSS-II Supernova Survey to Validate Type Ia Supernova Models



SDSS Supernova Project has spectroscopically identified more than 500 Type Ia supernovae, and obtained high-quality light curves and spectra for many of them *(Holtzman et al. 2009, Kessler et al. 2009)*

Comprehensive Systematic Validation of Type Ia Supernova Simulations Is Underway





[see poster]

What do we see as our legacies? Part 1 …

Transformational science legacies

- We created FLASH, a highly capable, modular, extensible community code, with a world-wide applications base, both within and outside astrophysics
- We transformed the Type Ia supernova field in astrophysics
- We transformed the ‘way of doing business’ in computational astrophysics:
  - Closely coupling code development with V&V
  - Coupling astrophysics-inspired experimentation with simulations

What do we see as our legacies? Part 2 …

Transformational institutional legacies

- We transformed the way Argonne and UofC interact:
  - Original PI of Flash Center became Director of Argonne (Prof. Robert Rosner)
  - UofC faculty re-engaged *at* Argonne: UofC retained Argonne management contract!
  - Argonne staff engaged at UofC

- We transformed computational science at UofC, Argonne, and beyond:
  - Flash Center's work led to creation of UofC Computation Institute (www.ci.uchicago.edu/)
  - Computational science faculty in A&A, Biosciences, CS, Math, …
  - Computational science courses across the Physical Sciences Division
  - Computing ALDship and BG/L-Q at Argonne
  - CMSO and JINA NSF Physics Frontier Centers
  - DOE/GNEP computational science program, centered at Argonne, bears imprint of ASC V&V philosophy (and key personnel: e.g., Andrew Siegel was a previous Flash Center code group leader)

… our student legacy

Two key FLASH developers have won PECASE awards (Paul Ricker and Michael Zingale)

GRAD STUDENT LAST NAME	FIRST NAME	ACADEMIC DEPARTMENT	ADVISOR	POSITION IN CENTER	DEGREE - MS or PhD	GRADUATION YEAR	FIRST EMPLOYER (post grad)	CURRENT EMPLOYER	CITIZENSHIP
Alexakis	Alexandros	Physics	Rosner	Astro	PhD	2004	Postdoctoral Fellow, Advanced Study Prog. NCAR	Researcher, Observatoire de la Cote d'Azur (Nice Observatory)	Greece
Biello	Joseph	A & A	Rosner	Astro	PhD	2001	Vigre Postdoctoral Fellow, Rensselaer Polytechnic Institute	Asst Prof. Dept. of Mathematics, U California, Davis	US
Caceres-Calleja	Alvaro	Physics	Rosner	Code	PhD	2006	Staff, MCS Division, ANL		Dual Switzerland/ Mexico
Cooray	Asantha	A & A	Hu/Lamb	Astro	PhD	2001	Research Fellow, Caltech	Asst Prof. Dept. of Physics & Astronomy, UCalifornia, Irvine	India
Curtis	Jennifer	Physics	Grier/Kadanoff	CS	PhD	2002	Postdoc, Biophysical Chemistry, UHeidelberg	Asst. Prof. Physics, Georgia Tech	
Donaghy	Timothy	A & A	Lamb	Astro	PhD	2006	Union of Concerned Scientists, Scientific Integrity Pr		
Draganescu	Andrei	Applied Math	Dupont	Basic Physics	PhD	2004	Sandia National Lab - Tech Staff, Optimization & Uncertainty Estimation Dep	Asst. P	
Dursi	Lewis	A & A	Rosner	Astro	PhD	2004	Postdoctoral Felllow, Institute for T Astroph		
Ganapathy	Murali	CS	Dupont	Code	PhD	2006			
Gomez	Ernesto	CS	Scott	CS	PhD	2005			US
Kleine Berkenbusch	Marko	Physics	Kadanoff	Basic Physics	PhD				German
Mignone	Andrea	A & A	Rosner	Astro				ino	Italy
Munoz-Franco	Lucia	A & A	Olinto/Truran					ysics book editor , Elsevier, Amsterdam	Spain
Oberman	Adam	Math	Const				ath,	Asst. Prof. Dept. of Mathematics, Simon Fraser University, BC, Canada	Canada
Peng	Fang						ostdoctoral Prize Fellow, Astronomy Dept., Caltech		China
Rebull	Luisa						Research Scientist, Spitzer Science Center, Caltech		US
Ruchayskiy						2003	Marie Curie Fellow, Institut des Hautes Etudes Scientifiques	Postdoc, Ecole Polytechnique Federale Lausanne	Russia
Schorgh						1998	Dept. of Physics, Chinese University of Hong Kong	Asst. Astronomer, NASA Astrobiology Institute, U of Hawaii, Manoa	US
				Astro	PhD	2008	Postdoc, Max Plank Institut fur Astrophysik, Garching, Germany		Germany
			Kadanoff	Basic Physics	PhD	2004	Research Assoc. Center for Nonlinear Studies, LANL	Postdoc, UConnecticut Health Center	Serbia
		GeoSci	Pierrehumbert	Basic Physics	PhD	2003	Postdoc, UCAR	Research Assoc. Applied Math, UWisconsin, Madison	
	zvan	Physics	Kadanoff	Basic Physics	PhD	2004	Postdoc, Physics Theory Group, Columbia University	Director's Fellow, Center for Nonlinear Studies, LANL	
	Brandy	Math	Constantin	Basic Physics	PhD	2005	Staff, National Security Agency		US
Wunsch	Scott	Physics	Kadanoff	Astro	PhD	1998	Sr. Technical Staff, SNL	Staff, Applied Physics Laboratory, Johns Hopkins U	US
Young	Yuan-Nan	A & A	Rosner	Astro	PhD	2000	Postdoctoal Fellow, Engineering Science & Applied Math, Northwestern University	Asst. Prof. Dept. of Mathematical Sciences, New Jersey Institute of Technology	China
Zhan	Shanqun	A & A		Astro	PhD	1998	Consultant, Recall (IT services); (IT services)	Owner, Evergreen Consulting Inc.	China
Zhyglo	Andriy	A & A	Khokhlov	Astro	PhD	2008	Postdoctoral Assoc. Physics, Florida State University		Russia
Zingale	Michael	A & A	Truran	Astro	PhD	2001	Postdoc, Astronomy and Astrophysics, UCalifornia, Santa Cruz	Asst. Prof. Dept. of Physics & Astronomy, SUNY Stony Brook	US
Zuhone	John	A & A	Lamb	Astro	PhD	2009	Postdoc, Smithsonian Center for Astrophysics, Harvard University		US

…our postdoc legacy

POSTDOC LAST NAME	FIRST NAME	ACADEMIC DEPARTMENT	ADVISOR	POSITION IN CENTER	YEARS AT FLASH	FIRST EMPLOYER	CURRENT EMPLOYER	CITIZENSHIP
Asida	Shimon	A & A	Truran/Lamb	Astro	2005 -2007	Prof. Rachah Institute of Phyiscs, Hebrew University of Jerusalem		Israel
Bal	Guillaume	Math	Dupont	Dickson Instr.	1999 - 2001	Assoc. Prof. Applied Physics & Math, Columbia University	Prof. Applied Physics & Math, Columbia University	France
Boldyrev	Stanislav	A & A	Rosner	Astro	2002 - 2006	Research Assoc. CMSO, UChicago	Asst. Prof. Dept. of Physics, UWisconsin, Madison	Russia
Brown	Ed	A & A	Truran	Astro	1999 - 2004	Asst. Prof. Dept. of Physics & Astronomy, Michigan State		US
Calder	Alan	A & A	Truran/Lamb	Astro	1999 - 2007	Asst. Prof. Dept. of Physics & Astronomy, SUNY Stony Brook		US
Cattaneo	Fausto		Rosner	Astro	1997 - 1999	Asst. Prof. Dept. of Mathematics, Uchicago	Assoc. Prof. Dept. of Astronomy & Astrophysics, UChicago	US/Italy
Donaghy	Timothy	A & A	Lamb	Astro	2006 - 2007	Analyst, Union of Concerned Scientists - Scientific Integrity Program		US
Dwarkadas	Vikram	A & A	Truran	Astro	2002 - 2003	Research Scientist, A & A, UChicago	Sr. Research Assoc. A & A, UChicago	India
Emonet	Thierry	A & A	Cattaneo	Astro	2000 - 2002	Research Scientist, Institute for BioPhysical Dynamics, UChicago	Asst. Prof. Molecular, Cellular & Developmental Biology, Yale	Switzerland
Fisher	Robert	A & A	Lamb	Astro	2005 - 2008	Asst. Prof. UMass - Dartmouth		US
Fryxell	Bruce	A & A	Rosner	Basic Physics	1998 - 2004	Research Scientist, Georgia State University	Research Scientist, Atmospheric, Oceanic & Space Sciences, UMichigan	US
Grigoriev	Roman	Physics	Kadanoff	Basic Physics	2000	Assoc. Prof. Center for Non-linear Science, Georgia Tech		Russia
Haque	Amer	A & A	Plewa/Dupont	CompPhys	2005 - 2007	Pursued Master of Engineering degree, IIT, Chicago	Adjunct Faculty, Applied Mathematics, IIT, Chicago	US
Hearn	Nathan	A & A	Plewa/Dupont	CompPhys	2005 - 2008	Project Scientist , NCAR		US
Heger	Alexander	A & A	Truran	Astro	2001 - 2003	Theoretical Astrophysics Group, T-6 Group, LANL & Adjunct Assoc. Prof. Physics, UCalifornia, Santa Cruz	Assoc. Prof. Physics & Astronomy, UMinnesota; Technical Staff, LANL	Germany
Huepe-Minoletti	Christian	JFI	Kadanoff	Basic Physics	2000 - 2002	Post Doctoral Fellow, Engineering Science & Applied Math, Northwestern U	Visiting Scholar, Engineering Science & Applied Math, Northwestern U	Chile
Jena	Tridivesh	A & A	Truran/Lamb	Astro	2005 - 2007	Research Scientist, UCSD	Consultant, Web Analytics	US
Josserand	Christophe	Physics	Kadanoff	Basic Physics	1997 - 1999	Researcher, Universite Pierre et Marie Currie,	National Center for Scientific Research, Paris	France
Kessler	Richard	A & A	Lamb/Frieman	Astro	2008	Sr. Research Assoc., A & A, UChicago/ Fermilab		US
Kirby	Robert	Math/CS	Dupont	Dickson Instr.	2000 - 2002	Asst. Prof. CS, UChicago	Assoc. Prof. Dept. of Mathematics, Texas Tech	US
Kirr	Eduard-Wilhelm	Math/CS	Dupont	Dickson Instr.	2002 - 2005	Asst. Prof. Dept. of Mathematics, UIUC		Romania
Kiselev	Alexander	Math/CS	Constantin	Dickson Instr.	1997 - 1999	Asst. Prof. Math, UChicago	Prof. Dept. of Mathematics, UWisconsin, Madison	US
Krasnopolsky	Rueben	A & A	Konigl/Truran	Astro	2000 - 2002	Post Doctoral Fellow, Astrophysics, UToronto		Argentina
Lewicka	Marta	Math/CS	Dupont	Dickson Instr.	2002 - 2005	Asst. Prof. Dept. of Mathematics, UMinn		Poland
Linde	Timur	A & A	Malagoli/Rosner	Code/ ComPhys	1998 - 2005	Senior Analyst, Temujin Fund Management, LLC		Estonia
Lou	Yu-Qing	A & A	Rosner	Astro	2001 - 2002	Prof. Physics, Tsing Hua University		China
Loy	Raymond	ANL	Lusk	CS	2001 - 2004	Senior Software Developer, HPC Apps Engineer, MCS Division, ANL		US
Malagoli	Andrea	A & A	Rosner	ComPhys	1998 - 2002	Financial Engineering, private sector, NY		Italy
Malyshkin	Leonid	A & A	Rosner	Astro	2001 - 2002	Research Scientist, CMSO, U Chicago		Russia

…our postdoc legacy (continued)

Meakin	Casey	A & A	Truran/Lamb	Astro	2006 - 2008	Postdoctoral Assoc., Steward Observatory, UArizona		US
Messer	Bronson	A & A	Truran/Lamb	Astro	2003 - 2005	R&D Staff, Ntl. Center for Computational Sciences, ORNL; Asst. Prof. Physics & Astronomy, UTennessee		US
Niarchos	Vasilis	Physics	Konigl/Rosner	Astro	2003	Postdoc, Niels Bohr Institute, Copenhagen	Postdoc, Center for Theoretical Physics, Ecole Polytechnique	Greece
Nie	Qing	Math	Dupont	Dickson Instr.	1997 - 1999	Asst. Prof. Math, UChicago	Prof. Dept. of Mathematics, Dir. Ctr. For Mathematical & Computational Biology, UCalifornia, Irvine	China
Niemeyer	Jens	A & A	Truran/Rosner	Astro	1998 - 2001	Prof. Dept. of Astronomy, Universitat Wurzburg	Prof. Physics, Georg-August-Unversitat Gottingen	Germany
Olson	Kevin	A & A	Fryxell	Code	1998 - 2001	Assoc. Research Scientist, NASA/GSFC	Re… …. Prof. Dept of Physics, …y	US
Pan	Hua	A & A	Plewa/Dupont	ComPhys	2003 - 2006	Research Felllow, Nanyang Techno… University	…cientist, Corvid …resville, NC	China
Plassmann	Paul	A & A	Rosner	Code	1997 - 1998	Prof. Electrical & Co…		US
Plewa	Tomasz	A & A	Dupont	ComPhys	2001 - 2007	Asst. Prof…		Poland
Poludnenko	Oleksiy	A & A	Kokhlov	Astro	2004 - 2006	Po…		US
Pugh	Mary	Math	Dupont	V & V	1999 - 20…			
Ryzhik	Lenya	Math	Dupont	Dickson Instr.	19…		…matics, UChicago &	US
Ricker	Paul	A & A	Lamb	A…			… Prof. Dept. Astronomy & Research Scientist, NCSA, UIUC	US
Schenkel	Alain	Math	Const…			…y, U of	Scientist, Computational Engineering Lab, Ecole Polytechnique Federale de Lausanne	Switzerland
Timmes	Frank					…, LANL	Chair, School of Earth & Space Sciences, Arizona State U	US
Townsley	Dean	A…				…art J. Bok Fellow, UArizona		US
Tufo	Henry	Al…			…2002	Scientist, Scientific Computing Div., NCAR	Assoc. Prof. Computer Science, UColorado, Bolder	US
Uzdensky	Dimitri	A & A			1999 - 2001	Postdoctoral Member, Kavli Institute for Theoretical Physics, Santa Barbara	Research Staff, Dept. of Astrophysical Sciences, Princeton	Russia
Vainstein	Samuel	A & A		Astro		Sr. Research Assoc., CMSO, UChicago	Retired	US
Vladimirova	Natalia	A & A	…sner	ComPhys/Basic Physics	1997 - 2005	Collaborator/Consultant, ASC Flash Center/LANL	Post Doctoral Fellow, Math & Statistics, UNew Mexico, Albuquerque	Russia
Vlahakis	Nektarios	A & A	Konigl/Rosner	Astro	2000 - 2003	Lecturer, Astrophysics, Astronomy & Mechanics, UAthens, Greece	Asst. Prof., Astrophysics, Astronomy & Mechanics, UAthens, Greece	Greece
Weirs	V. Gregory	A & A	Malagoli/Plewa	ComPhys/Basic Physics	1998 - 2004	Postdoc, SNL		US
Yu	Dahai	A & A	Plewa/Dupont	Comphys	2004 - 2006	Acxiom		China
Zhang	Ju	A & A	Plewa/Dupont	Astro/ ComPhys	2004 - 2006	Visiting Scholar, Computational Science & Engnieering, UIUC	Research Scientist, Computational Science & Engnieering, UIUC	China

Twenty-four postdocs
now hold faculty positions

Flash Center Awarded $9.3 M in FY 2009

Flash Center *6/6* for proposals submitted in FY 2009:

- ANL LDRD grant for period FY 2008-2010 ($340 K)
- UofC-Fermilab Strategic Initiative grant for period FY 2010-2011 ($104 K)
- NASA Applied Information Systems Research grant for period FY 2010-2012 ($120 K)
- NSF Physics at the Information Frontier grant for period FY 2010-2012 ($300 K)
- NSF Cyber Infrastructure Petascale Apps grant for period FY 2010-2013 ($2.2 M; $400 K to University of Chicago)
- NSF Astronomy & Astrophysics grant for period FY 2010-2014 ($2.25 M)

Partnership between DOE ASCR Office of Science and NNSA is supporting the addition of HEDP capabilities to *FLASH* for period FY 2010-2012 ($6 M) [see poster]

Did we attain our original three goals?

- ❑ Achieve significant science impact ✓
- ❑ Transform computational science at UofC and Argonne ✓
- ❑ Transform perception of UofC itself, and of its relationship with Argonne, both internally and externally ✓

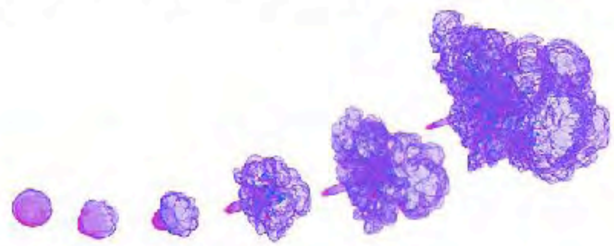
The level of effort expended did lead to the transformational legacies we demanded of ourselves

…along the way we brought visibility to NNSA, ASC, and the Academic Strategic Alliance Program

- Through the FLASH code -- which has been used by more than 650 scientists around the world
- Through the impact of the science done by the Flash Center
- By demonstrating the value of closely coupling code development and simulations to V&V
- Through the scientific discoveries made by the Center that received attention beyond the scientific community…

Discovery of New Type Ia SN Mechanism Is Lead Article in *Science Times* in 2004

Life-or-Death Question: How Supernovas Happen



Center for Astrophysical Thermonuclear Flashes/University of Chicago
A three-billion-degree bubble of thermonuclear hell mushrooms upward through a star in the milliseconds of a supernova explosion. Sweeping around the star's surface, the bubble could collide with itself, setting off a fatal detonation.

By DENNIS OVERBYE
Published: November 9, 2004

Once a second or so, somewhere in the universe, a star blows itself to smithereens, blossoming momentarily to a brilliance greater than a billion suns.

Nobody understands how these events, among the most violent in nature, actually happen. But, until recently, that didn't much matter unless you were a practitioner of the arcane and messy branch of science known as nuclear astrophysics.

Lately, however, supernovas have become signal events in the life of the cosmos, as told by modern science.

Using a particular species of supernova, Type 1a, as cosmic distance markers, astronomers have concluded that a mysterious "dark energy" is wrenching space apart, a discovery that has thrown physics and cosmology into an uproar.

As a result, the fate of the universe - or at least our knowledge of it - is at stake, and understanding supernovas has become essential.

Astronomers are busy on many fronts trying to figure out the details of these explosions - scanning the skies to harvest more of them in the act, peering at the remains of ancient supernovas to seek a clue to their demise, harnessing networks of supercomputers to calculate moment by moment reactions in the heart of hell.

This has resulted recently in a kind of two-steps-forward, one-step-back progress, encouraging astronomers that they are on the right track, generally, with their theories, but at the same time underscoring complexities and baffling puzzles when it comes to pinning down the details of what happens in the explosions.

Last month members of an international team of astronomers led by Dr. Pilar Ruiz-Lapuente of the University of Barcelona announced that they had found a star speeding away from the site of a supernova blast seen in 1572 by the astronomer Tycho Brahe. This supernova, which appeared as a "new star" in the constellation Cassiopeia, was one of the earliest studied by astronomers, and helped shatter the Aristotelian notion that the heavens above the Moon were immutable.

The newly discovered star, presumably the companion of the star that exploded, supports a long-held notion that such explosions happen in double star systems when one star accumulating matter from the other reaches a critical mass and goes off like a bomb.

Meanwhile, members of a group of astrophysicists using a network of powerful supercomputers to simulate supernova explosions say they have succeeded for the first time in showing how such a star could blow up.

Over the course of 300 hours of calculation at the University of Chicago's Center for Astrophysical Thermonuclear Flashes, otherwise known as the Flash center, they watched bubbles of thermonuclear fury rise from the depths of the star like a deadly jellyfish and then sweep around the surface and collide in an apocalyptic detonation that Dr. Donald Lamb, a Chicago astrophysicist, called "totally bizarre and novel."

If true, the Chicago results could help explain not only how stars explode, but why the explosions are almost but not exactly alike, allowing astronomers to better calibrate their measurements of dark energy.

Many supernova experts said, however, that such computer simulations were more of a good start than a final answer. Dr. J. Craig Wheeler of the University of Texas called the Flash center work "a courageous calculation," but added that many details needed to be filled in. "I don't think this is the end of the story," he said. The story of Type 1a supernovas, experts have long agreed, begins with a dense cinder known as a white dwarf, composed of carbon and oxygen, which is how moderate-size stars like the Sun, having exhausted their thermonuclear fuels of hydrogen and helium, end their lives.

If it happens to be part of a double star system, the white dwarf can accumulate matter from its companion until it approaches a limit, known as the Chandrasekhar mass - about 1.4 times the mass of the Sun.

At that point, so the story goes, the pressure and density in the previously dead star will be great enough to reignite the star and thermonuclear reactions will ripple upward, transmuting the carbon and oxygen into heavier and heavier elements, ripping the white dwarf apart while its companion goes flying off.

Until recently, however, there was little evidence of this. Two white dwarfs could collide, for example, and blow up. In that case there would be no survivor.

Tycho Brahe's supernova has now offered new evidence for the former model, of the white dwarf bomb.

That supernova is one of the few of Type 1a's that have occurred in our own galaxy, and so astronomers have long sought to find its companion. That star, astronomers reasoned, should be zinging along relative to its neighbors, as a result of having been released, like a stone from a slingshot, from its orbit around the suddenly deceased white dwarf.

The site of the supernova explosion is marked today by a small scruff of X-rays and radio waves in the sky.

Near the center of this patch the team found a sunlike star moving three times as fast as it neighbors.

The star has the right characteristics to have been the one donating material to the white dwarf that exploded, but the identification is not ironclad, a team member, Dr. Alex Filippenko of the University of California at Berkeley, said, explaining in an e-mail message that "it is 'possible' that the star just happened to be zooming through that region and is unrelated to the supernova."

ARTICLE TOOLS
- E-Mail This Article
- Printer-Friendly Format
- Most E-Mailed Articles
- Reprints & Permissions

TIMES NEWS TRACKER

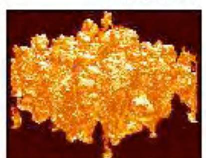
Topics	Alerts
Space	Create
Physics	Create

Track news that interests you.

Create Your Own | Manage
Most Popular Alerts | Take a Tour

CLICK HERE TO SUBSCRIBE

Enlarge This Image



Lawrence Berkeley National Laboratory
Gravity and buoyancy churn and warp the flame front in a star undergoing a supernova explosion. The front marks the boundary, as thick as a sheet of paper, where oxygen and carbon are being fused to heavier elements. Forty days and 40 nights on a supercomputer were required to produce this image, a patch about half a yard across.

Flash Center Type Ia Supernova Simulations Featured in March 2007 *Astronomy Magazine*

Supernova symphony

A SUPERNOVA DETONATES in a spiral galaxy in this illustration. These titanic explosions create and distribute most of the elements, stir up galactic gas and dust, and give astronomers beacons that shine across billions of light-years. ADOLF SCHALLER FOR ASTRONOMY

What makes stars explode?

Sound waves in collapsing stars may produce supernova explosions.

/// BY FRANCIS REDDY

No event in nature surpasses a supernova's raw power. The flood of neutrinos accompanying the explosion of a single massive star releases as much instantaneous power as the rest of the visible universe combined. Such blasts stir interstellar gas and dust, helping new stars to form. More importantly, supernovae disperse most of the elements heavier than carbon — such as the iron in our blood — and create neutron stars and black holes.

After decades of debate, astrophysicists still aren't sure how a star turns into nature's grandest firecracker. Even the most complex computer simulations haven't solved the problem, but they have served up some surprises. For instance, sound waves in a collapsing star's heart could help kick-start a stalled explosion, while a white dwarf's detonation may arise when the star's gravity turns a thermonuclear conflagration back on itself.

The big picture

By the 1930s, it was clear that some stellar flare-ups, called novae, were in a class by themselves. In 1933, astronomers Walter Baade at Mt. Wilson Observatory and Caltech's Fritz Zwicky began referring to the most luminous events as supernovae. They suggested the explosions occurred when a massive star collapsed and created a neutron star. Bear in mind this was more than 3 decades before pulsed radio signals from the Crab Nebula supernova remnant proved that neutron stars exist at all.

In 1941, Mt. Wilson's Rudolph Minkowski proposed supernovae come in two flavors based on the absence (type I) or presence (type II) of strong hydrogen spectral lines at peak brightness. Since then, the observational picture has become more complex as astronomers recognized new subclasses of both types. Nevertheless, astronomers generally agree that two scenarios likely account for most supernovae.

Type Ia occur in all galaxies among an older stellar population. All others — type II, plus types Ib and Ic associated with gamma-ray bursts — prefer galaxies sparkling with star-forming regions, which contain many hot, young, massive stars. Such stars explode when they use up their nuclear fuel and collapse.

Core collapse

Stars weighing more than about 8 times the Sun's mass burn through their hydrogen fuel quickly, but as a massive star runs low on one fuel, it taps into another. Its core contracts, growing hotter and denser until the previous nuclear reaction's "ash" — helium, at first — undergoes fusion itself. As each fuel runs out, the star's core responds in the same way, running through

Francis Reddy *is an associate editor of* Astronomy.

38 ASTRONOMY /// MARCH 07

Flash Center Type Ia Supernova Simulations Featured in March 2007 *Astronomy Magazine*

STELLAR BOMB

Companion star

Accreting white dwarf

A WHITE DWARF gobbles gas from its binary companion and gains mass. ASTRONOMY: ROEN KELLY

WHEN THE DWARF nears a mass threshold, the star's carbon ignites. A 10-billion-degree bubble of nuclear ash, seen here 1 second after ignition, starts rising to the surface.

There's enough acoustic power to blow the star apart half a second after core bounce in Burrows' simulation.

How important this process is remains an open question. It's the accreting material that keeps a lid on the explosion, preventing neutrinos from moving the shock out. "If the neutrino mechanism worked, we would have seen it in our model," Burrows says.

The sound waves push streams of accreting matter to one side of the core while energizing the shock on the opposite side. So, by creating a path of least resistance, sound may help neutrinos revitalize a stalled shock. "It's unproven," he says, "but very interesting." Moreover, the oscillating core could be a prominent source of gravitational radiation.

Shattered dwarfs

Large-scale computer simulations are also providing new insights into how white dwarfs, the end state of low-mass stars, destroy themselves as type Ia supernovae. Brighter and more uniform than core-collapse explosions, type Ia events are important probes of the distant universe. The discoveries of dark energy and cosmic acceleration add urgency to deciphering how they work.

A Sun-like star ends its days as a white dwarf, with the star's carbon-oxygen-rich core crushed to Earth's size. Most shine for billions of years, gradually cooling until they fade into dark stellar cinders. Electron pressure prevents further collapse, but it works only if the dwarf weighs less than 1.44 Suns — the so-called Chandrasekhar limit. Exceed that, and collapse resumes until the dwarf becomes a neutron star.

In 1960, University of Cambridge astronomer Fred Hoyle and Caltech's William Fowler realized a white dwarf near this limit could be a giant thermonuclear bomb. Place a white dwarf in close proximity to a normal star, and the dwarf can gain mass until it nears the 1.44-Sun threshold and explode. The dwarf gobbles up hydrogen gas from its partner at a probable rate of about 1/10 of an Earth-mass per year. If it's much slower than this, the dwarf's stellar wind prevents the gas from reaching the surface; if it's any faster, the gas will flash-fuse rather than accumulate.

As a white dwarf tips the scale toward 1.44 Suns, its carbon ignites somewhere inside. Before 2004, no one could figure out how to make a carbon-oxygen star detonate, so theorists first invoked turbulent thermonuclear fusion. These models failed to match the energy and element mix of type Ia blasts. Models that followed a period of turbulent burning with a detonation better matched reality, but theorists simply decided where and when the explosion would occur and inserted it into the simulation. "I sometimes refer to this as the 'Here, a miracle occurs' mechanism," says the University of Chicago's Don Lamb.

For this reason, Wolfgang Hillebrandt and his group at the Max Planck Institute for Astrophysics in Munich, Germany, tried a different tack. They found that models using turbulent burning alone can better match observations, but, to do so, the dwarf's thermonuclear fires must ignite in about 100 different points at once. That's very unlikely. Says Lamb: "We worry one miracle has been replaced by another."

In 2004, a team led by Alan Calder at the University of Chicago including Lamb, stumbled onto a way to blow up a white dwarf. Thanks to the U.S. Department of Energy's computational resources, the team had the hardware to simulate an entire white-dwarf star. After ignition, a narrow front of nuclear flame expanded through the star, leaving behind a 10-billion-degree ash bubble. When this bubble broke through the dwarf's crust, less than 10 percent of the star's mass had been fused — too little to disrupt the dwarf or produce a strong explosion. "It looked like it might be a dud," Lamb recalls.

Then, team member Tomasz Plewa performed additional 2-D simulations to see what happens after the bubble breeches the star's surface. The nuclear ash erupts, moving at around 6.7 million mph (10.8 million km/h), just shy of orbital speed. The hot cloud hugs the dwarf's billion-degree surface and rapidly spreads. As it does so, it plows up cooler, unfused surface matter. The superheated ash-cloud wraps around the white dwarf and meets itself at the point opposite its breakout. The collision compresses all of the unfused surface material, which explodes and rips the star apart.

The model, called "gravitationally confined detonation," is the most complete description of a type Ia supernova to date — and the only one in which a full-scale detonation naturally occurs. "It's a very promising model for most type Ia supernovae," Lamb says. "It was a serendipitous discovery. And it is a perfect example of how large-scale numerical simulations can lead to discoveries of complex, non-linear phenomena that are very difficult to imagine ahead of time," he adds.

Seventy-four years after astronomers connected supernovae with stellar deaths, the universe's most powerful explosions still tax astrophysicists. Yet, even the most complete simulations don't yet capture the complex environment of an exploding star. Modelers are beginning to probe how neutrino emission, magnetic fields, and rotation affect the picture. Observers watch and catalog new events, using them both as cosmic yardsticks and to find holes in current understanding. And new facilities designed to capture neutrinos and gravitational waves — signals that directly escape an exploding star's core — one day soon may give us a glimpse of a supernova's chaotic heart. ■

THE BUBBLE BREECHES the dwarf's surface 1.4 seconds after ignition in this simulation. The hot cloud of fusion products isn't moving fast enough to go into orbit. Instead, the dwarf's gravity confines the bubble to the star's surface (blue).

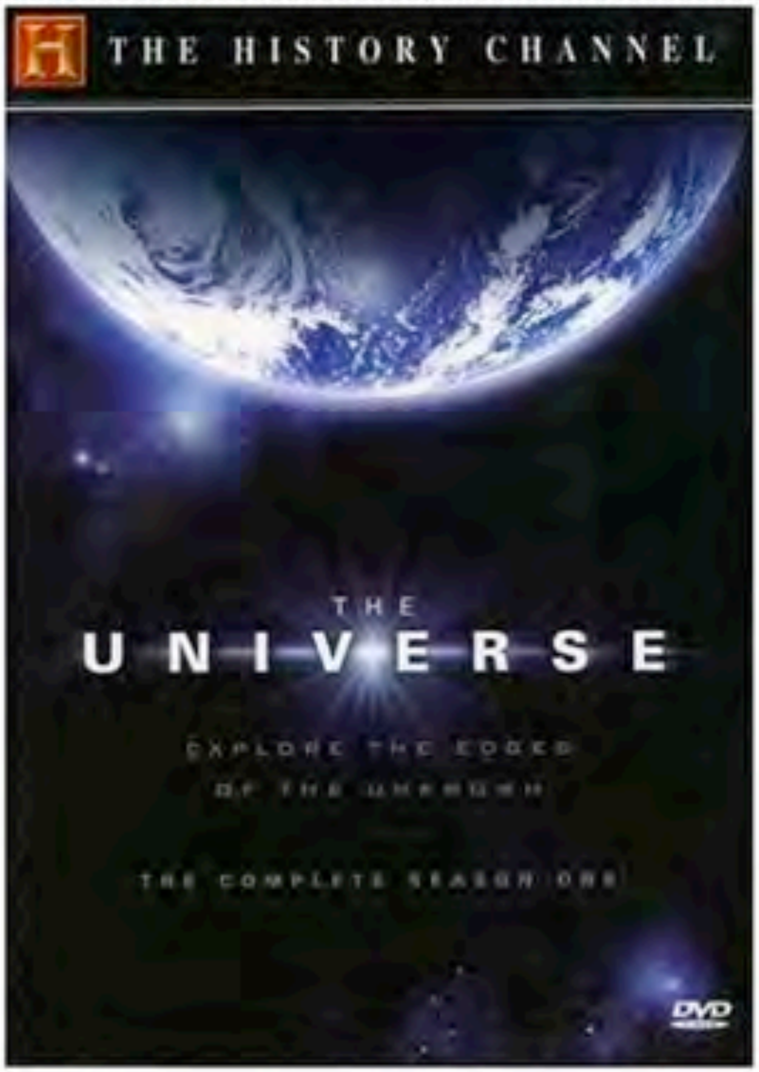
THE EXPANDING BUBBLE hugs the dwarf's surface and plows some of the star's unfused material ahead of it. We view the cloud 1.56 seconds after ignition — the last moment of the 3-D simulation by Calder's team. Following up with 2-D models, the astronomers showed this cloud wraps around the star in less than half a second. The cloud meets itself on the dwarf's opposite side. When it does so, the unfused surface matter the bubble plowed up crashes together and explodes, destroying the star.

TOMASZ PLEWA, ALAN CALDER, DEAN TOWNSLEY, SHIMON ASIDA, TRIDIVESH JENA, FANG PENG, IVO SEITENZAHL, JIM TRURAN, GEORGE JORDAN, CARLO GRAZIANI, JU ZHANG, ALEXEI KHOKHLOV, ANDREY ZHIGLO, ALEXEI POLUDNENKO, BRONSON MESSER, ED BROWN, AND DONALD LAMB (U.S. DEPARTMENT OF ENERGY ADVANCED SIMULATION AND COMPUTING PROGRAM, ALLIANCE FLASH CENTER, AND THE ARGONNE NATIONAL LABORATORY FUTURES LAB)

ONLINE EXTRA See movies of supernova simulations at www.astronomy.com/toc.

WWW.ASTRONOMY.COM 43

Flash Center Simulations of Type Ia Supernovae Featured on History Channel Beginning in 2008



- Movies of Flash Center simulations of Type Ia supernovae were shown and explained as part of the “Supernovas” episode in “The Universe” series
- Episode premiered on Sunday, February 17, 2008, at 10:00 CST
- Episode has aired many times since

Flash Center Type Ia Supernova Simulations Featured in *Science News*

Astronomers hope type Ia supernovas will help in quest to explain dark energy

By Ron Cowen

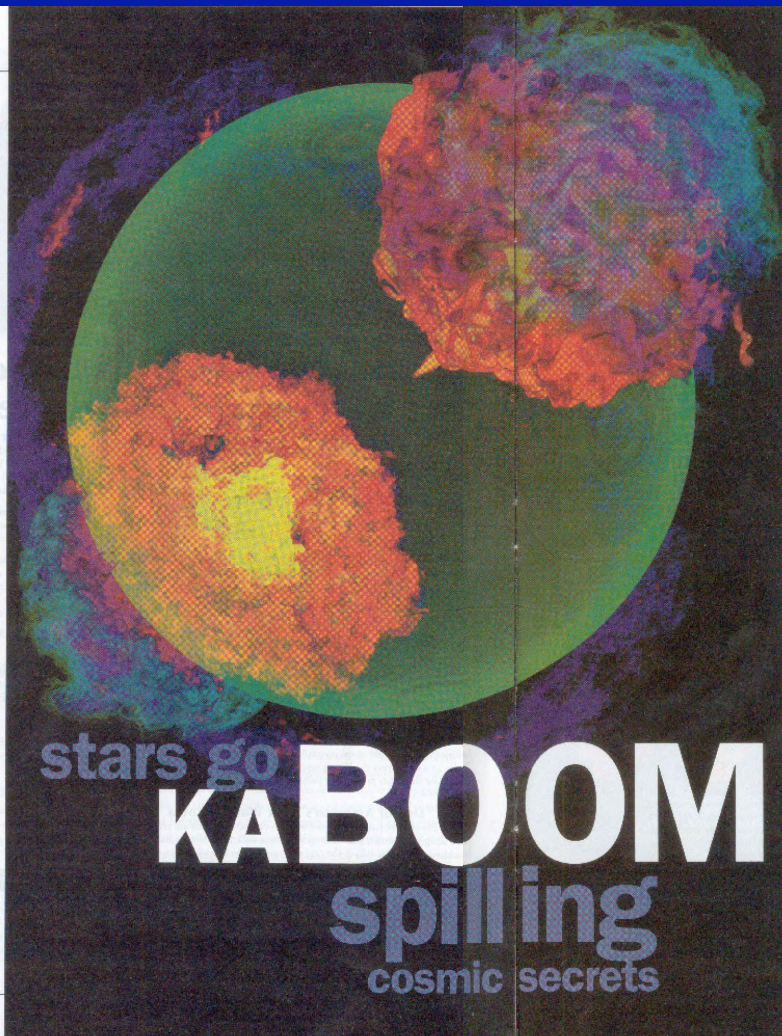
At least once a second, a dim, elderly star somewhere in the cosmos turns into a thermonuclear bomb. Briefly outshining its home galaxy, the explosion, known as a type Ia supernova, unleashes the equivalent of 10^{28} megatons of TNT — enough energy to destroy an entire solar system.

Astronomers have marveled at these cosmic firecrackers for centuries. But so far nobody has explained in detail how these supernovas explode. Now, theorists are on the verge of attaining that understanding — and just in time, because astronomers are observing type Ia supernovas with a new urgency. In fact, the story these stars have to tell is a matter of cosmic life and death.

When astronomer Robert Kirshner, now at Harvard University, first began observing these cataclysmic explosions in 1972, it didn't matter that no one understood how they happen. A lack of knowledge about the explosion process didn't stop Kirshner and his colleagues, along with another team, from using type Ia supernovas to discover in 1998 that a mysterious entity, later dubbed dark energy, is accelerating the expansion of the universe (*SN: 2/2/08, p. 74*). But today, ignorance about type Ia supernovas is no longer bliss, say Kirshner and other astronomers. Researchers now are not only relying on supernovas as distance markers to deduce the presence of dark energy, but also to unveil its character.

One of the deepest mysteries in all of physics and astronomy, the nature of dark energy determines the fate of the universe. If its density across the universe increases over time, the cosmos will end in a Big Rip, with every atom torn asunder. If it somehow vanishes, cosmic expansion will continue but at a slower rate. And if its strength remains fixed in time, akin to the cosmological constant that Einstein inserted into his equations of general relativity, every galaxy will someday become its own island universe.

ASC ALLIANCE, OFFICE OF SCIENCE INCITE PROGRAM/DOE, NASA, FLASH CENTER



An inwardly directed jet produced by the collision of hot ash along the surface of a white dwarf star penetrates the star and triggers detonation in this simulation. Green indicates the star surface, and yellow shows the hottest temperature.

To determine whether dark energy varies or remains the same throughout time, astronomers need to measure its equation of state, defined as the ratio of its density to its pressure. And to measure the equation of state at different epochs in the universe, researchers urgently need more detailed information on type Ia supernovas, says Don Lamb of the University of Chicago.

Theorists are beginning to crack the riddle of supernova explosions by borrowing some of the techniques — and computer codes — applied to a surprisingly down-to-Earth system: combustion in gasoline engines. Thanks to these codes, which require the processing power of supercomputers, researchers can now view the full three-dimensional evolution of a stellar explosion instead of a muted, one-dimensional facsimile.

On the computer screen, "it's like watching a fire consume a forest, you just see these flames working through the star, with all this structure to it," says theoretical astrophysicist Daniel Kasen of the University of California, Santa Cruz.

Simulations developed by supernova expert Stan Woosley, also of UC Santa Cruz, along with Kasen, Fritz Röpke of the Max Planck Institute for Astrophysics in Garching, Germany, and others now suggest that supernovas that erupted a few billion years back in time may be different — intrinsically brighter — than those exploding today. The team has begun to identify several other features that may affect supernova brightness — such as how rapidly a star rotated before it exploded and its abundance of elements heavier than helium — which might confound dark energy measurements if overlooked.

"We're starting to make meaningful comments about how useful these supernovae can be for precision cosmology," Woosley says.

Exploding stellar probes

Astronomers rely on type Ia supernovas to probe the expansion history of the universe because these explosions are almost perfect cosmic mile markers.

Since all Ia's appear to have the same starting point — blowing up the same amount of mass — they all should have roughly the same luminosity. After adjusting for variations by applying the Phillips relation, which holds that intrinsically brighter supernovas take more time to fade than dimmer ones, researchers can, in principle, read off the wattage of these cosmic lightbulbs. Just as the apparent brightness of a 60-watt bulb predictably diminishes with distance, so too should the observed brightness of a supernova.

When astronomers applied this prescription, they found that light from distant supernovas appeared dimmer than it ought to be based on what had been the accepted model of the universe's evolution. That unexpected result led in 1998 to an astonishing conclusion: Rather than slowing down, the cosmos has recently sped up its rate of expansion, putting extra distance between nearby and remote supernovas — and the galaxies in which they originated.

Now, astronomers want to know the inherent brightness of type Ia supernovas to within a few percent, rather than the previous error margin of 20 percent — and how that brightness varies among different populations. Suppose, for example, that supernovas containing a lower abundance of heavy elements — typical of stars earlier in the history of the universe — are on average intrinsically brighter than supernovas exploding today. The Phillips relation says that the supernovas with fewer metals should remain bright for a longer period of time than others. Indeed, models suggest that such cosmic

… which brings us to

Questions and Discussion